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A THEORETICAL APPROACH TO THE EVALUATION OF THE MORTALITY EFFECTS OF A 'LOW TAR' CIGARETTE*

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Abstract—The two parameter Gompertz hazard function is shown to fit Hammond's 1960 American Cancer Society life tables which depict survivorship of men aged 25–100 yr for five levels of smoking frequency. Using data on tar levels of cigarettes on the market during the period 1960–65, various models are proposed to estimate the covariation of the Gompertz parameters by smoking frequency and tar content. For each model, estimated life expectancy and age specific death rates are presented for various smoking frequency–tar groups and the mortality consequences of a 'low tar' and 'low frequency' public health policy are discussed. Multiple regression analysis is used to summarize the mortality findings and to provide a quantitative assessment of the relative importance of tar content and smoking frequency in determining life expectancy and death rate. Evidence from the models favors a 'low tar' policy over a 'low frequency' policy but considerable benefits can be obtained from a combined policy.

I. OBJECTIVES

RECENT smoking and health controversy has centered around the likely effects on human mortality of a federal policy sanctioning only the sale of 'low tar' cigarettes. At present, very little data are available to document the mortality effects of prolonged smoking of cigarettes at various tar levels. Moreover, ethical and practicality considerations preclude the possibility of a controlled clinical trial being performed to estimate these effects.

The objectives of this paper are thus to develop various mathematical models to:

1. Estimate the variation in various measures of mortality by daily smoking frequency and cigarette tar content.
2. Discuss implications of the mortality results in terms of public health policy that would encourage the use of 'low tar' cigarettes and/or encourage smokers to lower daily smoking frequency.

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II. BACKGROUND

The past 25 yr have seen considerable research showing association of cigarette smoking with diseases such as lung cancer, chronic bronchitis, emphysema and ischaemic heart disease. Most noteworthy of these studies were by Doll and Hill [1], who studied mortality in British physicians according to smoking habits, the Dorn study reported by Kahn [2] and Rogot [3] which was a prospective study of U.S. Veterans and the American Cancer Society (ACS) study of Hammond [4, 5] of one million men and women which is discussed in greater detail later in this paper. Preston [6] has reported a competing risks analysis of the ACS data.

There have been several attempts to infer a dosage response relationship between cigarette smoking and mortality. Waingrow *et al.* [7] developed a dosage score for American adults using data from the National Health Survey which considers daily smoking frequency, tar content of cigarette preference and portion of cigarette actually smoked, but no mortality consequences were presented. Various authors have studied the effect of skin painting with cigarette smoke condensate on the onset of skin cancer in mice [8–10]. The latter study [10] reported a linear relationship between log dose (measured in mg condensate) and tumorigenic response. Hammond [11] studied survival of dogs trained to smoke cigarettes of various tar levels and found an inverse relationship between survival and tar level. A retrospective study by Bross and Gibson [12] defined exposure in terms of 'years smoked', 'daily frequency' and 'filter or non-filter' and were able to show mortality advantages for those who switched from non-filter to filter cigarettes.

III. METHODOLOGY

A. 1960 *American Cancer Society (ACS) survival curves*

Hammond [5] has presented survival data by daily smoking frequency derived from 5 yr survival experience of 447,000 men, aged 33–92 in 1960 and followed until 1965. These survival curves are age-standardized to the 1959–61 U.S. life table population. By making minimal assumptions, survival curves for males aged 25–100 are presented for daily smoking frequencies 1–9 cigarettes, 10–19 cigarettes, 20–39 cigarettes, and 40+ cigarettes and for those who never smoked regularly. These survival data are reproduced in Table 1.

B. *Gompertz hazard function*

It was decided to attempt to fit the Gompertz hazard function to the ACS survival curves. This function and its associated survival function and probability density function are derived as follows:

1. Let y = age at death $\quad t = y - 25$ then:

hazard function:

$$\lambda(t) = k\,e^{at}, \qquad t \geq 0 \qquad (1)$$

survival function:

$$\mathscr{F}(t) = \exp - \left\{ \frac{k}{a}(e^{at} - 1) \right\}, \qquad t \geq 0 \qquad (2)$$

TABLE 1. AMERICAN CANCER SOCIETY, LIFE TABLES

Aged (yr)	All men (%)	Never smoked regularly (%)	Smokers: Current no. of cigarettes/day 1–9 (%)	10–19 (%)	20–39 (%)	40+ (%)
25	100.0	100.0	100.0	100.0	100.0	100.0
30	99.1	99.4	99.1	99.1	99.1	98.8
35	98.2	98.7	98.1	98.1	98.0	97.3
40	96.8	97.8	96.6	96.5	96.5	95.1
45	94.6	96.4	94.2	94.0	93.8	91.0
50	91.1	94.4	90.6	90.0	89.3	85.6
55	85.6	90.9	85.9	83.8	82.5	77.7
60	78.1	85.5	77.8	75.3	73.5	67.1
65	67.8	77.7	67.3	63.4	61.1	54.0
70	55.2	66.7	52.4	47.7	45.9	40.0
75	41.2	52.3	36.2	33.3	30.3	25.7
80	26.7	35.6	20.6	18.6	18.1	14.3
85	13.6	19.2	7.3	8.5	7.2	6.5
90	4.9	7.0	2.2	2.2	2.2	2.1
95	1.0	1.5	0.5	0.5	0.5	0.4
Life Exp.	70.2	73.6	69.0	68.1	67.4	65.3

Source: Hammond [5].
Survivorship of men aged 25 in relation to current number of cigarettes smoked per day: Based on rates adjusted to the 1959–61 U.S. life table for all males.

probability density function:

$$f(t) = k \cdot \exp\left\{at - \frac{k}{a}(e^{at} - 1)\right\}, \quad t \geq 0. \tag{3}$$

Maximum likelihood estimation of the parameters a and k, when only a frequency distribution of survival time is available, can be achieved through an assumption that survival time is discrete, occurring only at the median of each age interval [13].

2. Estimation of the parameters a and k.

Let $j = j^{th}$ age interval, $j = 1, 2, \ldots, J$

d_j = number of deaths in the j^{th} age interval

t_j = median of t in j^{th} age interval

n = sample size.

Solve for a:

$$n\left[\frac{\sum_1^J d_j t_j}{n} - \frac{\sum_1^J t_j d_j e^{at}}{\sum_1^J d_j e^{at_j} - n} + \frac{1}{a}\left(\frac{\sum_1^J d_j e^{at_j}}{\sum_1^J d_j e^{at_j} - n} - \frac{n}{\sum_1^J d_j e^{at_j} - n}\right)\right] = 0 \tag{4}$$

then:

$$\hat{k} = \frac{\hat{a}n}{\sum_1^J d_j e^{at_j} - n}. \tag{5}$$

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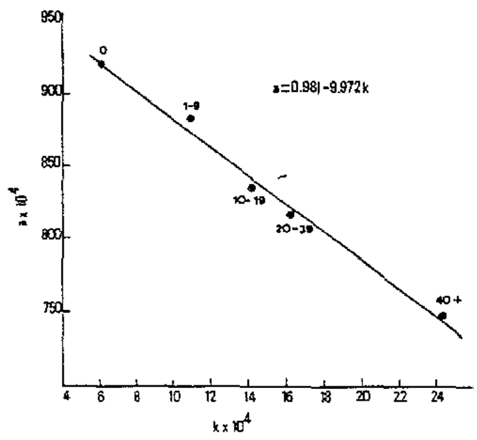

FIG. 1. Graphical display of estimates of Gompertz parameters (a, k) for American Cancer Society lifetables.

Using formulas (4) and (5) the Gompertz function was fitted to the five survival curves in Table 1. The nature of formulas (4) and (5) indicate that estimates of parameters a and k ($\hat{a}$ and $\hat{k}$) should be linearly correlated. Figure 1 shows that the $(\hat{a}, \hat{k})$ values tend to lie near the straight line:

$$a = 0.0981 - 9.972\,k \tag{6}$$

where the coefficients are estimated by least squares. The chi square test found no evidence of a significant difference between the observed and fitted survival

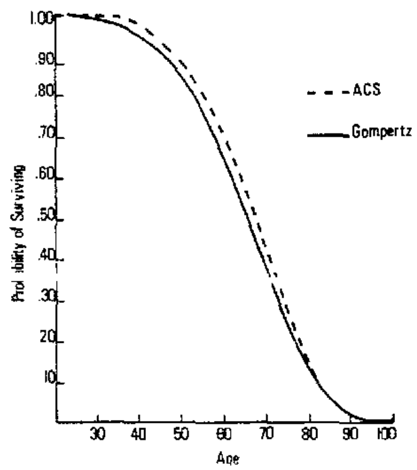

FIG. 2. Survival curves 20–39 cigarettes/day.

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C. *Smokin*

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D. *Model fo*

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TABLE 2. Pi

Tar rating
1
2
3
4
5
Total
N
Percentage
Average Ta
Average Fr

Source: W.

distributions at level 0.05. Figure 2 shows the observed (ACS) and fitted (Gompertz) survival curves for smokers who smoked 20–39 cigarettes/day.

C. *Smoking preferences of U.S. males*–1960–65

In order to estimate the effect of cigarette tar content on survival in the ACS cohort it is necessary to know the distribution of tar content of cigarettes smoked by smoking frequency for the period 1960–65. Waingrow *et al.* [7] reported such data from the 1964 National Health Survey. The distribution for males is shown in Table 2. Frequency groups have been combined in order to conform with intervals used by Hammond [5]. It is interesting to note that the distribution of tar rating is similar among the various frequency levels.

D. *Model formulation*

The models that will allow us to draw inferences on how the (a, k) values might vary between the 20 tar–frequency groups in Table 2 are based on the following assumptions:

1. The (a, k) values for any smoking frequency–tar rating combination lie on the straight line given by formula (6). Once k is known, a can be estimated using (6). The technique for estimating k leads us to our next assumption.
2. k is estimated by:

$$k = g_1(x) \tag{7}$$

(g_1 is a real-valued function and x is the 'dosage')

$$x = g_2(f, r) \tag{8}$$

(g_2 is a real-valued function of f and r where f = smoking frequency in cigarettes per day; r = tar level of the cigarette in mg).

The analytic procedure to be followed will be as follows:

(a) Select a function g_2 to define dosage.

(b) To choose the function g_1 that will allow us to estimate k from x, we find the function that best explains the relationship between the values of k estimated

TABLE 2. PERCENTAGE DISTRIBUTION OF TAR RATING BY DAILY SMOKING FREQUENCY U.S. MALES, 1960–65

	Frequency (cig./day)					Tar level (mg)	
Tar rating	1–9	10–20	21–40	40+	Total	Range	Mean (r)
1	0.5	0.3	0.4	0.7	0.4	5–10	8
2	10.4	9.6	8.1	9.2	9.1	11–20	15
3	24.5	29.7	31.9	30.5	29.9	21–30	25
4	30.2	25.5	23.5	22.0	25.0	31–40	35
5	34.4	34.9	36.1	37.6	35.6	41–45	42
Total	100.0	100.0	100.0	100.0	100.0	5–45	25
N	192	384	540	141	1257		
Percentage Dist-Freq.	15.3	30.5	43.0	11.2	100.0		
Average Tar	32.7	32.5	32.6	32.5	32.5		
Average Freq. (f)	5.6	15.5	27.0	47.6	22.5		

Source: Waingrow *et al.* [7].

from each of Hammond's four smoking frequencies (the group that never smoked regularly is not considered here) and x computed using g_2. The value of f used is the conditional mean of each smoking frequency group computed from data presented by Waingrow *et al.* [7] and displayed at the bottom of Table 2. The value of r to be used is the average tar by smoking frequency also shown at the bottom of Table 2.

(c) Once g_1 is determined k is estimated from x using (7) and a is estimated from k using (6).

(d) With (a, k) estimated, survival curves, life expectancies, and age specific mortality rates can be computed for each of the 20 frequency–tar combinations in Table 2. The values of f and r used in these calculations are shown in Table 2.

E. *Proposed models*

For the purpose of this paper, the following models were used:

$$x = g_2(f, r) = d_0 \ln f + d_1 \ln(q_0 + q_1 r) \tag{9}$$

$$x = g_2(f, r) = f^{d_0}(q_0 + q_1 r)^{d_1} \tag{10}$$

$$x = g_2(f, r) = (d_0 f + d_1 r)^2 \tag{11}$$

$$x = g_2(f, r) = (d_0 \ln f + d_2 \ln r)^2. \tag{12}$$

Formulas (9–12) were chosen to give representation to both additive (9), multiplicative (10) and interaction (11, 12) models as well as original scale (10, 11) and log scale (9, 12) models. The models were used with a wide range of values of d_0, d_1, q_0, and q_1.

In all cases the relationship between k and x was best explained by:

$$\hat{k} = g_1(x) = e^{b_0 + b_1 x} \tag{13}$$

the coefficients b_0, b_1 being estimated by least squares by performing linear regression of ln k on x.

The results of (1), (6) and (13) may be combined by rewriting the hazard function as:

$$\lambda(t) = k \cdot e^{(0.0981 - 9.972\,k)\,t}$$

where $k = e^{b_0 + b_1 x}$.

The IBM 370/145 computer was programmed to generate Gompertz parameter estimates for each of the 20 frequency–tar combinations under models (9–12) for various values of d_0, d_1, q_0, and q_1. For each specific model a table was generated giving life expectancy and death rate/1000 for the 45–54 yr age group.

F. *Public health policy*

For each model an estimate of life expectancy and death rate for 45–54 yr old males under a 'low tar' policy is made. This assumes that in each smoking frequency group 25% of the smokers would smoke a tar rating 1 (5–10 mg) and the remaining 75% would smoke a tar rating 2 (11–20 mg) cigarette.

Similarly estimates are made under a 'low frequency' policy in which all 20–39 cig./day smokers would join the 10–19 cig./day group and all 40+ cig./day smokers would reduce their frequency to 20–39 cig./day. Inspection of Table 2

shows that the resulting distribution of smoking frequency would be 15.3% at 1–9 cig./day. 73.5% at 10–19 cig./day and 11.2% at 21–39 cig./day.

Estimates under a combined low tar–low frequency policy are also presented.

IV. RESULTS

A. *Non-smokers*

The estimated life expectancy and annual death rate per 1000 males 45–54 for non-smokers are shown in Table 3. These estimates result from the Gompertz fit to Hammond's [5] survival curves for the ACS cohort that 'never smoked regularly'.

B. *Smokers*

Of the many models generated for smokers, four were selected for presentation. They were selected to represent each of the four types of model (models (9–12)) and on the basis of 'plausibility'. The term 'plausibility' represents a minimum requirement that Hammond's [5] ACS estimated life expectancies and death rates/1000 males 45–54 for men smoking 0–9, 10–19, 20–39, and 40+ cigarettes/day should fall within the range of values given by the model at each frequency level. This criterion is based on the assumption that the men in the ACS cohort were smoking cigarettes with tar levels within the range of those accounted for by the five tar rating groups and thus their mortality experience should fall within the range of that depicted by the model.

The four models selected were:

$$x = g_2(f,r) = \ln f + \ln r \tag{14}$$

$$x = g_2(f,r) = f^{0.5} r^2 \tag{15}$$

$$x = g_2(f,r) \doteq (f + 2r)^2 \tag{16}$$

$$x = g_2(f,r) = (0.5 \ln f + 0.7 \ln r)^2. \tag{17}$$

They correspond, in form, to models (9–12) respectively.

Under each model life expectancy and annual death rate per 1000 males 45–54 yr were computed for each of the 20 frequency–tar combinations. These results are displayed in Tables 4–7. At the bottom of each frequency column under 'All tar ratings' are Hammond's [5] estimates by smoking frequency from the ACS study and the composite estimate given by the model. The latter is computed by taking a weighted average of the estimates over the five tar rating groups using the distribution of tar by smoking frequency in Table 2. Also shown is the 'low tar' estimate described above. The 'All frequencies' columns show the composite estimate by

TABLE 3. COMPARISON OF MEASURES OF MORTALITY FOR NON-SMOKERS

	ACS	Gompertz
Life expectancy	73.60	73.54
Death rate/1000 45–54 yr old	5.87	6.25

TABLE 4. MORTALITY RESULTS FOR MODEL (14) $x = \ln f + \ln r$

Tar rating	Life expectancy (yr) Smoking frequency (cig./day) 1–9	10–19	20–39	40+	All frequencies Model: 1960–65	Low freq.
1	73.1	70.5	69.2	68.0	70.0	70.8
2	71.5	69.0	67.8	66.8	68.7	69.3
3	70.2	67.9	66.9	65.9	67.5	68.1
4	69.4	67.3	66.3	65.5	67.0	67.5
5	69.0	66.9	66.0	65.2	66.4	66.9
All tar ratings						
ACS: 1960–65	69.0	68.1	67.4	65.3		
Model: 1960–65	69.7	67.5	66.5	65.6	67.1	67.7
Low tar	71.9	69.4	68.2	67.1	69.0	69.7
	Death rates/1000 males aged 45–54					
1	6.62	8.74	10.06	11.48	9.42	8.61
2	7.88	10.24	11.64	13.10	10.69	9.98
3	9.02	11.53	12.95	14.37	12.19	11.38
4	9.82	12.39	13.81	15.15	13.09	12.34
5	10.27	12.86	14.26	15.55	13.73	12.93
All tar ratings						
ACS: 1960–65	9.22	11.47	12.82	15.77		
Model: 1960–65	9.56	12.08	13.50	14.86	12.62	11.85
Low tar	7.57	9.87	11.25	12.70	10.37	9.64

TABLE 5. MORTALITY RESULTS FOR MODEL (15) $x = f^5 r^2$

Tar rating	Life expectancy (yr) Smoking frequency (cig./day) 1–9	10–19	20–39	40+	All frequencies Model: 1960–65	Low freq.
1	72.1	72.0	71.9	71.7	72.0	72.1
2	71.6	71.2	70.9	70.5	71.1	71.2
3	70.5	69.5	68.6	67.6	69.0	69.5
4	69.0	67.1	65.9	64.8	66.5	67.2
5	67.7	65.5	64.6	63.8	65.0	65.5
All tar ratings						
ACS: 1960–65	69.0	68.1	67.4	65.3		
Model: 1960–65	69.3	67.7	66.7	65.8	67.3	67.8
Low tar	71.7	71.4	71.2	70.8	71.3	71.4
	Death rates/1000 males aged 45–54					
1	7.38	7.48	7.55	7.66	7.53	7.48
2	7.75	8.10	8.39	8.79	8.23	8.07
3	8.71	9.79	10.69	11.95	10.31	9.76
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	11.79	15.00	16.87	16.83	15.67	15.12
All tar ratings						
ACS: 1960–65	9.22	11.47	12.82	15.77		
Model: 1960–65	10.11	12.17	13.59	14.50	12.73	12.01
Low tar	7.66	7.95	8.18	8.51	8.06	7.92

tar rating computed as a weighted average of the frequency specific estimates. The weights may be determined using the data in Table 2. The 'low frequency' estimate described above is also shown.

The models are reasonably consistent in their estimates of overall life expectancy and 45–54 yr death rates to the ACS cohort. The range of estimated life expectancy is 67.1–67.4 while estimated deaths per 1000 range from 12.50 to 12.73.

The results can be summarized by considering the relative benefits of reducing tar content and/or smoking frequency for smokers in various tar–frequency groups as predicted by the four models. For a smoker of 40+ cigarettes/day at tar rating 5, the models predict 2.8–7.9 extra years of life and 4.07–9.17 fewer deaths/1000 males 45–54 for reducing to a tar rating 1 cigarette and 2.8–3.9 extra years of life and 4.80–5.51 fewer deaths per 1000 males 45–54 for reducing frequency to 1–9 cigarettes/day. Only model (14) showed a greater benefit for reducing frequency than reducing tar. For smokers in this group reducing both frequency and tar the models predict 7.7–8.3 extra years of life and 8.93–9.94 fewer deaths/1000 males 45–54.

For the smoker of 20–39 tar rating 3 cigarettes/day the models predict 2.3–3.3 extra years of life and 2.76–3.93 fewer deaths/1000 males 45–54 for reducing smoking frequency to 1–9 cigarettes/day. Model (14) showed a greater benefit for reducing frequency rates than tar content while model (17) showed about equal benefit for each and models (15) and (16) favored reducing smoking frequency. For smokers in this group reducing both frequency and tar the models predict 3.5–6.2 extra years of life and 3.31–6.33 fewer deaths per 1000 males 45–54.

The implication of the 'low tar' and 'low frequency' policies defined above can be summarized on the basis of overall life expectancy and death rates. The models predict from 1.9–4.0 extra years of life and 2.25–4.67 fewer deaths per 1000 males 45–54 yr under the 'low tar' situation described above. For the 'low frequency' situation described above the models predict from 0.5–0.6 extra years of life and 0.72–0.79 fewer deaths per 1000 males 45–54 yr. All four models predicted greater benefits for 'low tar' than 'low frequency'. Under a combined low tar–low frequency situation the models predict 2.6–4.1 extra years of life and 2.98–4.81 fewer deaths per 1000 males 45–54 yr.

The relative importance of smoking frequency and tar content on life expectancy and death rates may be quantified through multiple regression analysis. The regression model

$$Y = B_0 + B_1 f + B_2 r + \epsilon$$

where ϵ is the random error term

Y = life expectancy or death rate

f = smoking frequency (Table 2)

r = tar content (Table 2)

gives a very good fit to the estimated life expectancies and death rates for models (14–17) in Tables 4–7. Table 8 shows the results of these multiple regression analyses. The multiple correlation coefficient (R) exceeds 0.938 for all models. Attention is directed to the standardized regression coefficients (b'_1, b'_2) which are scale invariant. Their ratio $Q = b'_2/b'_1$ may be interpreted as the relative importance of tar

r	
frequencies	
5	Low freq.
	70.8
	69.3
	68.1
	67.5
	66.9
	67.7
	69.7
	8.61
	9.98
	11.38
	12.34
	12.93
	11.85
	9.64

quencies
Low freq.
72.1
71.2
69.5
67.2
65.5
67.8
71.4
7.48
8.07
9.76
1_.00
15.12
12.01
7.92

TABLE 6. MORTALITY RESULTS FOR MODEL (16) $x = (f + 2r)^2$

Tar rating	1–9	10–19	20–39	40+	Model: 1960–65	Low freq.
	Life expectancy (yr)					
	Smoking frequency (cig./day)				All frequencies	
1	72.1	71.7	71.1	69.6	71.2	71.7
2	71.5	70.9	70.1	68.3	70.4	70.9
3	70.2	69.4	68.4	66.4	68.7	69.4
4	68.5	67.6	66.5	64.8	66.8	67.5
5	67.2	66.2	65.3	64.4	65.5	66.1
All tar ratings						
ACS: 1960–65	69.0	68.1	67.4	65.3		
Model: 1960–65	68.8	68.0	67.0	65.5	67.4	68.0
Low tar	71.7	71.1	70.4	68.6	70.6	71.1
	Death rates/1000 males aged 45–54					
1	7.38	7.69	8.22	9.66	8.23	7.74
2	7.86	8.35	9.12	11.05	8.87	8.35
3	9.01	9.82	10.98	13.61	10.68	9.85
4	10.83	11.99	13.52	16.30	13.37	12.21
5	12.52	13.87	15.48	17.32	15.19	14.16
All tar ratings						
ACS: 1960–65	9.22	11.47	12.82	15.77		
Model: 1960–65	10.60	11.66	13.04	15.35	12.50	11.65
Low tar	7.74	8.19	8.90	10.70	8.71	8.19

TABLE 7. MORTALITY RESULTS FOR MODEL (17) $x = (0.5 \ln f + 0.7 \ln r)^2$

Tar rating	1–9	10–19	20–39	40+	Model: 1960–65	Low freq.
	Life expectancy (yr)					
	Smoking frequency (cig./day)				All frequencies	
1	73.2	71.4	70.4	69.2	71.0	71.6
2	71.7	69.7	68.6	67.4	69.4	69.9
3	70.3	68.3	67.1	66.1	67.7	68.4
4	69.4	67.3	66.3	65.3	66.9	67.5
5	68.8	66.8	65.8	65.0	66.2	66.8
All tar ratings						
ACS: 1960–65	69.0	68.1	67.4	65.3		
Model: 1960–65	69.7	67.7	66.6	65.7	67.3	67.9
Low tar	72.1	70.1	69.1	67.9	69.8	70.3
	Death rates/1000 males aged 45–54					
1	6.53	7.92	8.88	10.04	8.47	7.85
2	7.70	9.53	10.76	12.17	9.98	9.35
3	[illegible]	11.14	12.56	14.10	11.85	11.03
4	9.88	12.34	13.84	15.35	13.15	[illegible]
5	10.45	13.02	14.53	15.96	14.00	13.12
All tar ratings						
ACS: 1960–65	9.22	11.47	12.82	15.77		
Model: 1960–65	9.59	11.95	13.40	14.88	12.54	11.75
Low tar	7.41	9.13	10.29	11.64	9.60	8.98

TABLE 8. RESULTS OF MULTIPLE REGRESSION ANALYSIS $\hat{Y} = b_0 + b_1 f + b_2 r$

Model no.	R	b_0	b_1	b_2	b'_1 (Standard coefficients)	b'_2 (Standard coefficients)	$Q = b'_2/b'_1$
Y = Life expectancy							
14	0.938	72.827	−0.096	−0.096	−0.734	−0.584	0.80
15	0.970	75.141	−0.057	−0.198	−0.326	−0.913	2.80
16	0.995	74.334	−0.076	−0.160	−0.510	−0.854	1.67
17	0.961	73.753	−0.091	−0.126	−0.645	−0.712	1.10
Y = Death rate/1000 males 45–54							
14	0.961	5.922	0.117	0.114	0.759	0.590	0.78
15	0.947	3.396	0.072	0.232	0.341	0.883	2.59
16	0.984	4.004	0.098	0.196	0.521	0.834	1.60
17	0.970	4.942	0.110	0.149	0.658	0.712	1.08

content to smoking frequency in determining life expectancy or death rate. For determining both the expectancy and death rate the data of Table 8 show that model (14) indicates smoking frequency more important than tar content while models (15–17) find tar content more important although to varying degrees.

V. DISCUSSION

The preceding analysis is intended to provide input for those interested in the relative effects of preventive medicine policy centered around sanctioning the sale of 'low tar' cigarettes only and educating smokers to reduce smoking frequency.

A majority of the models seem to indicate greater mortality benefits in reducing tar content than smoking frequency although considerable benefits are found in reducing both. All four models indicate greater benefits in the 'low tar' situation than the 'low frequency'. It is realized that public health specialists may prefer alternatives to the specific 'low tar' and 'low frequency' situations presented here. The data in Table 2 and Tables 4–7 may be used to evaluate the mortality effects of these alternatives. The multiple regression equations for models (14–17) in Table 8 may be used to estimate life expectancy and/or death rates for additional specific levels of tar content and smoking frequency.

There are of course some limitations in the applications of the models presented above. The models describe the interaction of the cigarette market, cigarette preferences and smoking frequencies that existed in the early 1960's when Hammond [5] and Waingrow *et al.* [7] collected their data. Smoking habits and the cigarette market may have changed over the past decade. The models consider only dosage factors of tar content and smoking frequency assuming the effects of 'age began smoking', 'portion of cigarette smoked', 'degree of inhalation', etc. are constant in each of the frequency–tar groups. It is believed that the approach described above represents a useful beginning to a theoretical basis for the formulation of a public health policy on cigarette smoking.

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